

THE CONTROL OF SPACECRAFT CONTAMINATION --
WHERE ARE WE GOING?

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The last conference exclusively on the subject of spacecraft contamination that I attended was held in 1969 as Aspen, Colorado. A review of the program from that conference shows that most of the topics discussed then were also discussed here in Colorado Springs, nearly nine years later. Therefore, it seems appropriate to spend some time reviewing where we are and discussing where we are going with respect to spacecraft contamination control.

The NASA Contamination Control Handbook⁽¹⁾ defines "contaminant" as "any material, substance, or energy which is unwanted or adversely affects the contaminee."

Because this definition can include a wide range of contaminants, it would be worthwhile to eliminate some types of control activities that are already adequately covered by other groups. For example, radio frequency interference could fall within the above definition of a contaminant, but it is typically considered as a separate technical specialty.

Background radiation of other types is of importance to the accomplishment of space missions. For example, the use of magnesium alloys containing thorium 232 may result in unacceptably high levels of background gamma radiation for some scientific experiments. Other potential gamma sources include potassium 40 in potassium silicate paints and uranium 238 found in some glasses. This can affect the selection of materials for use with some experiments.

Spacecraft contamination control was derived from the technologies developed for aircraft and missile systems. Fluid systems had to be free from particulates that could damage components; liquid and gaseous oxygen systems had to be free of materials that could react with the fluid; and a "visually clean" environment was maintained for good housekeeping. Procedures and equipment were developed to control the particulate environment, and instruments became available to monitor the environment. It would appear that the control of particulate and organic contaminants in fluid systems are, for the most part, adequate to meet the needs of spacecraft systems.

More stringent cleanliness requirements resulted from the needs of components using high speed bearings and the manufacture of miniature electronics components. The technology for these areas of contamination control appear to be satisfactory to meet the needs of spacecraft systems, although all the problems have not been solved.

During orbital operations, it soon became apparent that there were additional types of contamination problems. Spacecraft windows have become clouded; thermal control surfaces have degraded at higher than anticipated rates; and, particulates around spacecraft have appeared as false targets for star sensors.

Thermal-vacuum tests on spacecraft and components revealed large quantities of outgassing materials that condensed on cooler surfaces. Vacuum bakeout of components was initiated to reduce the condensable products, but this was not always satisfactory. Screening tests were initiated to help select materials for minimum outgassing, and some new materials were formulated using specially processed, low-outgassing constituents. We now have an ASTM standard screening test for materials⁽²⁾, and most spacecraft programs exercise controls on the use of materials. The move towards the use of the Space Shuttle System is resulting in more programs now employing the same criterion as is used in the NASA Space Shuttle specification for vacuum stability of polymeric materials.⁽³⁾

The typical screening test criterion is less than 1% of TML (total mass loss) and less than 0.1% CVCN (collected volatile condensable material). This provides the type of quantitative requirement that is needed for inclusion in contract work statements and for the initial selection of potentially satisfactory materials. I emphasize "initial selection" and "potentially satisfactory" because this is just the first step in the selection of materials. The functional performance of materials, including contamination, often requires additional tests on materials and components. These additional tests are used to provide information on the performance of materials for specific applications. These functional tests may be tailored to the use in one system or may be more general in nature. Final proof of satisfactory material selection and processing usually occurs during ground thermal-vacuum tests, or, unfortunately, sometimes not until in orbit.

Waiting until a system is in orbit to have some confidence in the performance is not the ideal approach. Designers and systems engineers want to know the effect of using specific quantities of known materials under the predicted temperature environments.

The large number of papers on modeling presented at this conference is evidence of the importance of providing engineers with quantitative predictions of the contamination on spacecraft systems.

I have formulated a list of topics and added some comments that I hope will serve as a basis for discussions during this morning's session.

1. Standards and Requirements
2. Cleaning
3. Ground Operations
4. Contamination Monitoring on the Ground and In-Flight
5. Rocket Motor Plumes
6. Modeling
7. Systems Engineering

Standards and requirements are closely related subjects. It is necessary to define the required cleanliness and to have suitable techniques to verify that the requirements have been achieved. Some requirements state that the components shall be clean but do not define "clean." "Visibly clean" is being specified, but this requires well defined procedures. Other requirements have merely specified "Class 100,000" or "Class 10,000" environment per FED-STD-209.⁽⁴⁾ It is important to distinguish between the "Class of a clean room" and the "Class of the environment." FED-STD-209⁽⁴⁾ defines the general requirements for a clean room, and additional requirements are defined in references 5 and 6. A clean room class is based on the design, construction, and operating procedures. In addition, the actual cleanliness can vary over a wide range depending upon the number of people in the room and the types of operations being performed. For example, a Class 10,000 room can provide a Class 5,000, or even a Class 100 environment, when appropriate procedures are used.

The significance of the above is that it may be necessary to specify the required environment in addition to the class of clean room. For example, a system that has been operating in a Class 100,000 clean room may be exposed to no greater than a Class 10,000 or 5,000 environment for most of the time. If a Class 100,000 environment is specified and maintained, the system may not achieve the required cleanliness levels. It should be noted that standard HEPA (high efficiency particulate air) filter⁽⁷⁾ provides Class 100 or cleaner air.

Although it is necessary to specify the work environment, the primary goal is the maintenance of a clean spacecraft rather than a "clean room."

The procedures being used in a clean area can be much more important than the design of the room.

One area of extreme concern for many space system applications is that clean room standards do not consider molecular contaminants that may deposit onto exposed surfaces.^(4,5,6) A review of additional references on contamination control specifications and standards^(8,9) also do not appear to include molecular contaminants.

This includes outgassing from materials and dioctylphthalate (DOP) used to test clean rooms and HEPA filters. Liquid DOP is atomized to form aerosol droplets of approximately 0.3 μm in diameter. Holes in the filter and leaks in the system can then be detected using a standard particle counter. Unfortunately, DOP can be a contaminant, especially for optical surfaces.

Clean room and filter standards, such as references 4 through 7, should be revised to incorporate controls on molecular contaminants because many applications of clean facilities do not require controls on molecular contaminants; therefore, the standards should contain the necessary options for alternate verification techniques. For example, the NASA Johnson Space Center allows the use of a probe and particle counter to scan filters for defects.⁽¹⁰⁾

There is a definite need for quantitative descriptions of surface cleanliness. The current approach is to use MIL-STD-1246A⁽¹¹⁾ or NASA SN-C-0005⁽¹²⁾ to describe particulates and NVR (non-volatile residue) on surfaces. These standards define the numbers of particulates per unit surface area as a function of size. One drawback to requiring a specific cleanliness level per MIL-STD-1246A or SN-C-0005 is that it becomes necessary to measure both the numbers and sizes of particulates to satisfy the letter of the requirement. This is difficult because a spacecraft usually cannot be cleaned and verified by the standard procedures used for small components. For components, a typical procedure is to flush them with solvent, collect and filter the solvent, and then count and size the particles that have been removed. The solvent flushing technique is not practical for the total spacecraft, and it only measures what has been removed from the surface, not what remains on the surface.

Photographic techniques have been used for non-contact or limited contact with a surface.⁽¹³⁾ In addition, techniques such as vacuuming surfaces and the

use of pressure sensitive adhesive tapes to remove particulates have been used. Each of these techniques has limitations.

Witness surfaces that are kept with the spacecraft and are removed for measurement on a scheduled basis provide an additional approach to monitoring cleanliness without having to contact sensitive areas. This requires that the witness surfaces be exposed to exactly the same environment as the spacecraft. The human element enters into the measurement because it may not be possible to verify that the witness surfaces are not given special treatment during the various spacecraft operations. Workers may treat the witness surfaces very carefully while leaving fingerprints on the spacecraft surfaces.

For many components, the cleanliness can be evaluated by measuring a quantity related to the function of a component. For example, the cleanliness of optical and thermal control surfaces can be evaluated by measuring their performance. Because it may not be convenient to measure the surfaces directly, optical techniques can be used in conjunction with witness plates.

Particulates or non-uniform molecular deposits on surfaces can be detected by measuring the increase in scattered light from highly specular witness plates (such as mirrors). Deposited molecular contaminants can be detected by the increase in infrared light absorption on plates used for multiple internal reflectance spectroscopy.^(14,15)

Contaminants from rocket motors are still a matter of concern as they were in 1969. Since that time, considerable analytical and experimental work has been performed on bipropellant and monopropellant thrusters, resulting in the development of the CONTAM model.⁽¹⁶⁾ There is a current effort being sponsored by the Air Force Rocket Propulsion Laboratory to revise the model. The Shuttle Orbiter RCS and VCS thrusters were designed to minimize the production of contaminants.

Unfortunately, solid propellant thrusters have not been adequately studied. Several areas need to be studied with analytical and experimental programs. These include the composition of contaminants in the exhaust plume (molecular and particulate) and the motion of small particles in the gas plume.

Another aspect of modeling includes the total spacecraft system in flight. Design studies have been performed in support of the Space Shuttle Orbiter system, and studies on fundamental mechanisms of contaminant sources and transport are in progress. The prediction of the effects of contaminants is still

difficult; however, in spite of the shortcomings of modeling and prediction, the technique is proving to be extremely useful. This is especially true in the identification of potential problems. The accuracies of the techniques are still uncertain, but, I believe that contamination analyses will become as important and standard in the near future as thermal analyses are now.

The systems engineering and management aspects of contamination control are as important as the technical aspects. It may be technically possible to achieve a particular objective, but it is necessary to consider cost. This gets back to defining requirements. A cleanliness requirement that is more stringent than necessary for mission performance can result in higher program costs. Requirements that are deficient can result in premature failure and performance degradation that can also increase costs. The cost aspect may become more important in the Space Shuttle era when anything that affects ground turn around times will also affect costs.

Because contamination control involves many different technologies and affects systems from design through flight operations, management at the Project Office level becomes more important.

In closing, although the titles of the presentations and the subject matter of today's conference appear similar to those of nine years ago, there have been significant accomplishments and contributions to spacecraft performance.

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